See deletions on pp. 17, 37 & 46. cMP

INSECTS IN RELATION TO NATIONAL DEFENSE

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Circular 22

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FUMIGATION

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June 1941

INSECTS IN RELATION

TO

NATIONAL DEFENSE

Circular 22 - Fumigation

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INTRODUCTION

For the control of insect pests that are troublesome in barracks, houses, warehouses, storerooms, or in foods and fabrics of all kinds that are stored therein or in other types of enclosures or storage places, there is no method more quickly effective than fumigation. By fumigation is meant the releasing of a poisonous gas or vapor within an enclosure and maintaining a poisonous atmosphere long enough to kill any insects present. There are several fumigants from which to choose, and many factors governing their successful use. A discussion of the commonly used fumigants, the uses for which each one is best adapted, and the various factors affecting its efficiency and safe use follows:

FUMIGATION - A SPECIALIZED ART

Fumigation is a specialized operation. Its effectiveness in insect control depends upon the exactness and skill used in its application. Most fumigants are highly toxic and dangerous to handle. Experience and close attention to details is essential. It therefore usually is best to have general fumigation work done by professional fumigators who make a practice of the art and guarantee their work. All parts of the country are serviced by reliable fumigation concerns that are available on short notice and have the proper equipment for doing the work. In some cases and for certain types of work, defense agencies and other large organizations may wish to keep a special corps of workers especially trained to carry on fumigation work.

ALL FUMIGANTS DANGEROUS

Any fumigants that are toxic to insects are also toxic to human beings. It therefore is necessary to take every precaution to avoid exposure to heavy concentrations of them. If in the application of fumigants it becomes necessary to expose oneself to the vapors, or if it is necessary to enter a building under

fumigation in order to open it for ventilation or any other purpose, an effective gas mask of the proper type should be worn.

Gas masks are available, equipped with especially designed canisters for removing dangerous vapors from the air breathed through them. A special canister is required for use with each different type of fumigant, and it should not be taken for granted that any canister that happens to be attached to the mask will afford protection against all gases. Since the life of a canister is limited, care must be exercised to see that new ones are supplied whenever those in use show signs of weakness. Operators should familiarize themselves with the construction and use of a gas mask, and should test the mask for possible leaks before entering concentrations of fumigants.

It must also be realized that fumigants can be absorbed directly through the skin so that it should not be taken for granted that by merely wearing a gas mask full protection will be obtained. Heavy concentrations are particularly dangerous and exposure to them for more than a few minutes should be avoided even though a mask be worn.

GAS MASKS

Gas masks consist essentially of a face piece and a canister. The most popular and commonly used type in this country has a breathing tube connecting the face piece with the canister. In some cases a skeleton type mask is used, the face piece being eliminated. The nostrils are closed by clamps and the wearer breathes through a rubber device that is inserted and held in the mouth.

The type popular in this country consists of a face piece of rubber or rubberized fabric which can be adjusted to fit tightly across the forehead, along the cheeks and under the chin, and is connected by a short flexible and non-collapsible tube to a sheet metal canister containing absorbent materials. A light harness or knapsack is provided to suspend the canister from the shoulders or to strap it to the chest. The face piece is provided with shatter proof glass eye pieces and with a check valve through which exhaled air escapes. At the bottom of the canister is a check valve which opens only to admit air

For each of the gases likely to be encountered in fumigation work, an especial canister is available. Most canisters are charged with materials intended to absorb only a limited number of closely related gases, although the all-service canister is designed to afford protection from a combination of gases. A color code has been adopted by the Bureau of Mines whereby canisters designed for different gases are assigned specific colors. A list of gas masks of different makes that have been tested and approved by the Bureau of Mines is given in Bureau of Mines Information Circular 7030.

Information regarding the type and make-up of canisters used for protection against the fumigants referred to in this bulletin is given in table 1.

Table 1.- Types of canisters used with gas masks for protection against the common fumigants.

Color of canister	Protection afforded	Contents of canister
White	Against low concentrations (less than 2% in air) of acid gases such as Hydrocyanic acid*, and sulphur dioxide.	Soda lime, caustic pumice, or caustite, which is a sodium hydroxide preparation, activated charcoal.
Black	Against low concentrations (less than about 2% in air) of organic vapors such as carbon disulphide, methyl bromide, carbon tetrachloride, ethylene dichloride, chloropicrin, ethylene oxide.	Activated charcoal.
Yellow	Against low concentrations (less than 2% in air) of a combination of organic vapors and acid gases, such as a combination of hydrocyanic acid and chloropicrin.	Activated charcoal and soda lime or other alkaline granule.
Red	Against low concentrations of combinations of preceding gases - the all-service canister.	Contains a suitable combination of the absorbents mentioned above.

* With 2% hydrocyanic acid gas in the air, absorption of the gas through the skin is rapid enough to cause poisoning after 3 minutes' exposure; 1 percent is dangerous after 10 minutes and 0.5 percent may produce symptoms after 30 minutes.

The life of a canister is limited. As supplied by the manufacturer it is sealed by a cap over the inlet valve at the bottom and by a cork in the hose nipple. The contents may deteriorate under some circumstances even without use. If in testing a gas mask too much resistance to breathing is encountered, the canister should be replaced. With regard to the life of the all-service canister Forbes and Grove (1937) make the following statement:

"When poisonous gases, except carbon monoxide, pass successively into the canister, the canister expends a portion of its life or capacity in absorbing each gas. The break or approach to the end of canister life permits a very small quantity of poisonous gas to pass, and gradually more and more passes. The life of the canister when subjected successively to different gases usually equals the sum of the part or fractional lives based on the life for each gas alone but may be longer if the successive gases are of a different class.

"For example, if the canister were used to one-half its life or capacity against sulphur dioxide, it would retain one-half of its original life against hydrocyanic or other acid gas and more than one-half its life against organic vapors and ammonia. The passage of pure dry air does no harm to the life of the canister against any gas except carbon monoxide. The respective absorbents fail only when saturated with absorbed gas or vapors to the point where they can no longer restrain all the gas that enters. Poisonous gases can be noticed by odor, taste or eye irritation. When penetration of a gas is sensed, the wearer must go to fresh air immediately, and the canister must be discarded for a new one."

FIRST AID

In case of poisoning by toxic gases or asphyxiation due to lack of oxygen, a doctor should be summoned as quickly as possible. Forbes and Grove (1937) suggest the following treatment:

1. Remove the victin to fresh air as soon as possible.

2. If breathing has stopped, is weak and intermittent, or is present in only occasional gasps, artificial respiration, preferably by the prone-pressure method, should be given persistently until normal breathing is restored or until it is definitely believed that the heart action has stopped.

3. Circulation should be aided by rubbing the limbs of the victim and keeping the body warm with blankets, hot-water bottles, hot bricks, etc.

4. It cannot be emphasized too strongly that inhalation of pure oxygen or 5 to 7 percent carbon dioxide and 95 to 93 percent oxygen, beginning as soon as possible and continuing for 20 to 30 minutes in mild cases and as long as 1 or 2 hours, if necessary, in severe cases, will greatly reduce the severity of carbon-monoxide poisoning and decrease the possibility of serious after-effects. This treatment will also be helpful in gas poisoning or asphyxiation.

5. The victim should be kept at rest, lying down to avoid strain on the heart;later he should be given plenty of time to rest and recuperate.

CHARACTERISTICS OF THE COMMON FUMIGANTS

Of the many poisonous gases that are toxic to insects there are a limited number that are particularly well adapted to the needs of the fumigator. However, not all of these are equally satisfactory for all types of fumigation work. Some are well adapted for the treatment of large enclosures, such as houses, barracks, or warehouses, while others are suitable only for use in tight vaults or bins. Each fumigant has different characteristics, a knowledge of which is essential for their intelligent use. The physical properties of the common fumigants are given in table 2 and further discussion of them in alphabetical order follows.

Carbon Disulphide

Carbon disulphide is one of the heavier-than-air fumigants that is well adapted for the treatment of commodities stored in bins or tight containers. Unfortunately, its value for this purpose is greatly limited owing to the highly inflammable nature of its vapors which restricts its use to situations where the fire hazard can be effectively controlled. The pure liquid chemical which is about one-fourth heavier than water, has a sweetish, not unpleasant odor, but the commercial chemical is often decidedly yellowish in color, due to the excess of sulphur and has a disagreeable odor due to the hydrogen sulphide contained in it. On exposure to air it evaporates slowly, forming a heavy vapor that diffuses rapidly downward rather than upward. Its power of penetrating bulk commodities is remarkable, a feature which combined with its high toxicity to insects makes it the most effective known fumigant for treating bulk grain in bins.

Table 2.- Physical Properties of Common Fumigants

Fumigant	Formula	Molecular weight	Boiling point at 760 mm. °C.	Liquid density (water=1) at 20°C.	Limit of inflammability in air, percent by volume		Weight per gallon pounds	Lbs. required to saturate 1,00 cu. ft. of space at 77° F.
					Lower	Upper		
Carbon disulphide	CS_2	76.13	46.3	1.261	1.06	50. +	10.5	91.2
Carbon tetrachloride	CCl_4	153.84	76.8	1.595			13.3	59.1
Chloropicrin	CCl_3NO_2	164.39	112.4	1.692			13.8	13.1
Ethylene dichloride	$C_2H_4Cl_2$	98.947	83.7	1.257	6.2	15.9	10.5	26.4
Ethylene oxide	C_2H_4O	44.05	10.7	0.887	3.	80.	7.3	112.5
Hydrocyanic acid	HCN	27.03	26.0	0.699	5.6	40.	5.7	66.9
Methyl bromide	CH_3Br	94.95	4.6	1.732*	13.5	14.5	14.4	242.4
Naphthalene	$C_{10}H_8$	128.16	217.9	1.145			solid	0.04
Paradichlorobenzene	$C_6H_4Cl_2$	147.01	173.	1.458			do.	0.5
Sulphur dioxide	SO_2	64.06	-10.	1.434*			solid (sulphur)	163.7

* at 0 degrees C.

Carbon disulphide vapor is highly poisonous to human beings, producing giddiness, vomiting, congestion, coma and finally death if breathed in concentrated form for a protracted period. In its ordinary use for treating small quantities of grain or other commodities in bins or tight boxes the worker is not likely to experience more than a slight giddiness. The first symptoms of carbon disulphide poisoning are a numbing of the senses, the power of thought is weakened as well as hearing and sight. More or less dizziness occurs and the fumigator works in a mechanical sort of way. Men working where the gas is present should get out into the fresh air at the first signs of dizziness.

As previously stated, the vapors of carbon disulphide in admixture with air are highly inflammable and explosive and may ignite from any form of fire or even without the presence of flame at temperatures of 212° F. or above. Fire insurance is void while carbon disulphide is being used. It should be remembered that lighted lanterns, cigars, pipes, cigarettes, pilot lights in gas stoves and heaters, sparks from electric switches, static or frictional electricity, sparks caused by hammering upon metal, or even hot steam pipes may cause an explosion of the vapor. For this reason it should be used only for the treatment of bins, boxes and small enclosures segregated from buildings and where danger from fire can be avoided.

Carbon disulphide ranges in cost from about 6 cents a pound in 500-pound lots to 30 cents a pound or more in 1-pound lots. Firms dealing in chemicals and insecticides usually sell it in 5-gallon cans for about 95 cents a gallon.

Carbon Tetrachloride

Carbon tetrachloride is a colorless, non-inflammable liquid, with a pungent, aromatic odor. It evaporates, but slowly, when exposed to air, forming a vapor that is not highly effective against insects when used alone. Its chief value is for mixing with more toxic fumigants, such as ethylene dichloride, to reduce the fire hazard, and with less volatile fumigants, such as chloropicrin, to hasten vaporization and aid distribution by increasing the volume of the fumigant. It has an anaesthetic effect upon man, similar to chloroform, and while not highly toxic in weak concentrations, care should be taken not to expose oneself to the fumes of this fumigant or any mixture containing it for any extended period without wearing a gas mask.

Chloropicrin

Chloropicrin may be used as a general fumigant for large enclosures, such as houses, or warehouses, for the treatment of grain in bins and for other bulk commodities in vaults. It is a colorless or slightly yellowish liquid, a little more than one and one-half times as heavy as water, that volatilizes slowly on exposure to air.

Chloropicrin is non-explosive and non-inflammable as ordinarily used for fumigating purposes, and is extremely toxic to insects. It has the disadvantage of being slow in action, difficult to vaporize and disagreeable to handle because its vapor is a very irritating tear-gas and has a nauseating effect. Its vapor clings tenaciously to fumigated commodities and seriously affects the germination of grain and seed if the moisture content is high. When present in flour, chloropicrin has a deleterious effect on its baking qualities. This effect disappears when the flour is aerated.

The eye-irritating property of chloropicrin vapor is such that it is improbable that anyone would willingly enter an atmosphere containing an appreciable quantity of it. A gas mask with properly designed canister should always be worn while applying this material and care should be taken not to spatter the liquid on the hands or feet, since blistering of the skin may result.

According to Underhill (1919), the toxic action of chloropicrin to man is somewhere between that of chlorine and phosgene. Exposure to the gas causes coughing, nausea and vomiting and in large quantity, it may cause unconsciousness. Secondary effects are bronchitis, shortness of breath, a weak, irregular heart beat, and gastritis. It may also cause acute nephritis. Chloropicrin injures the lining of the respiratory tract, especially the medium and small bronchi. An overwhelming edema of the lungs rapidly follows exposure to a lethal concentration of the gas. Splashes of chloropicrin on the skin may be washed off with alcoholic di-sodium sulphite to prevent ulcerations. Affected eyes may be bathed with boric acid or a 2 percent solution of sodium bicarbonate.

Chloropicrin can be purchased in one-pound glass bottles or in cylinders of from 1 to 100 pounds capacity at a cost of $1.20 per pound for 1-pound cylinders down to 85 cents per pound in 100-pound lots.

Ethylene Dichloride

Ethylene dichloride is particularly useful as a fumigant for stored grain and seed in bins, and for the treatment of fabrics, garments, and furs in vaults or other tight containers. Although its vapors are inflammable it has been found that by mixing it with carbon tetrachloride in the proportion of 3 parts by volume of the ethylene dichloride to 1 part by volume

of carbon tetrachloride a non-inflammable mixture is obtained. This, from the standpoint of fire hazard, is safe to use under all ordinary conditions.

Ethylene dichloride is a colorless liquid with an odor somewhat resembling chloroform. On exposure to air it vaporizes rather slowly and if applied to the surface of a bin of grain the vapors will penetrate to all parts of the bin in a satisfactory manner. It can be used to treat seeds of all kinds without fear of injury to the germination regardless of the dosage and exposure, and is harmless to fabrics. The vapors are not quickly toxic to man in concentrations ordinarily used, but they have an anaesthetic action and care must be taken to avoid exposure to them for an appreciable period without using a gas mask.

Ethylene dichloride in admixture with carbon tetrachloride can be purchased in 55-gallon drums for about 6 1/2 to 7 cents per pound. In smaller quantities it can be purchased for about 75 cents per gallon.

Ethylene Oxide

Ethylene oxide is suitable for the treatment of many commodities in atmospheric vaults. It does not injure fabrics or furs or leave any obnoxious odor or poisonous residue on food stuffs. The concentrated vapor of ethylene oxide is inflammable but concentrations up to 3 1/2 pounds per 1,000 cubic feet of space are non-explosive and non-inflammable. Although it is used alone for some purposes it is better to use it in admixture with carbon dioxide. A non-inflammable mixture consisting of 1 part by weight of ethylene oxide to 9 parts of carbon dioxide is available commercially and is excellent for use in atmospheric vaults.

Ethylene oxide is a colorless liquid at low temperatures but on exposure to air it evaporates with great rapidity. It is supplied in cylinders under light pressure. As ordinarily used the dangers from breathing the vapors of ethylene oxide are not considered to be great. However, precautions taken against breathing the vapors should be the same as with any dangerous gas.

The liquid ethylene oxide is marketed in cylinders containing 75 or 195 pounds at a cost of about 26 cents per pound f.o.b. the factory. In smaller quantities the cost is higher. The mixture of ethylene oxide and carbon dioxide is sold in 30- and 60-pound cylinders under high pressure at prices ranging from 14.5 to 16 cents per pound, f.o.b. the factory.

Hydrocyanic Acid

For the fumigation of all types of buildings, such as houses, barracks, or warehouses, there is no more efficient gas than hydrocyanic acid. Since it kills with great rapidity it can be successfully used in enclosures that are incapable of holding fumigants for long periods and in which other less toxic gases are useless. It is also excellent for use in atmospheric vaults and will not injure most articles of commerce. It is a deadly poison but can be handled with reasonable safety by experienced fumigators. Hydrocyanic acid is a colorless, volatile liquid that is inflammable and that burns like alcohol when ignited. In the vapor stage, when mixed with air at concentrations used in ordinary fumigation it is non-inflammable and non-explosive.

In fumigation work hydrocyanic acid gas is commonly produced in four ways: (1) by the evaporation of the liquid acid pumped into the enclosure

from cylinders; (2) by generating it in a barrel or other container from a mixture of sodium cyanide and dilute sulphuric acid; (3) by evaporating it from discoids of an absorbent material impregnated with the liquid; (4) by exposing to the air, in thin layers, a powder containing calcium cyanide, which combines with the atmospheric moisture to produce hydrocyanic acid gas.

Owing to the high toxicity of hydrocyanic acid the cost of fumigating with it is not high. The cost will vary, however, with the method by which the gas is produced. It is cheapest when generated by the barrel method. Liquid hydrocyanic acid is sold for $1 per pound. Sodium cyanide can be purchased in 100-pound lots for about 16 cents per pound and sulphuric acid for approximately 4 cents per pound in 11-gallon carboys. Discoids sell for $1.20 per pound in one-pound cans. Calcium cyanide dust ranges in price from $1.60 per lb. in one-pound cans to $1.20 per pound in 25-pound cans.

With regard to the effect of hydrocyanic acid on man, Flury and Heubner state that from 40 to 50 milligrams of hydrocyanic acid per cubic meter are tolerated without serious injurious after effects. The latter concentration may produce headache, nausea, and vomiting. Sixty to 70 milligrams of HCN per cubic meter constitute the danger limit and 100 milligrams per cubic meter (about 1/10 oz. per 1,000 cubic feet) and over may cause death. According to the U. S. Public Health Service (1929), concentrations of from 140 to 180 milligrams per cubic meter are dangerous on exposure from 30 minutes to one hour, and exposure to concentrations greater than this kills in a short time.

Methyl Bromide

Methyl bromide is useful as a general fumigant for buildings of modern, tight construction and for the treatment of certain bulk commodities in atmospheric vaults. It does not kill insects so rapidly as hydrocyanic acid, hence is not effective in loosely constructed buildings that are incapable of holding the gas for any appreciable length of time. It is not recommended for the fumigation of foodstuffs that have a high fat content ~~or for milled cereal products~~ intended for human consumption since these products retain quantities of residual bromides that may be harmful.

Methyl bromide is a colorless gas that is sold commercially in liquid form in cylinders. It is under sufficient pressure so that a cylinder will empty itself if the valve is opened. It is non-inflammable at concentrations used in commercial practice, penetrates bulk commodities with remarkable facility and can be used successfully at comparatively low temperatures. It lacks a distinctive odor and is but faintly noticeable in small amounts, a feature that creates a hazard not present with some of the rapidly toxic gases that possess distinctive warning properties.

According to the United States Public Health Service (1929), "It is a little more toxic than gasoline, chloroform, and carbon tetrachloride for very short exposures and is markedly more toxic than these compounds in exposures of 30 minutes or more." Exposure to the gas may result in nausea, vertigo, visual disturbances, headache, loss of appetite and, in severe cases, to paralysis of the extremities, delirium, convulsions, epileptiform attacks or even death.

Referring to the human hazard connected with the use of methyl bromide for fumigation, the United States Public Health Service (1938) states that

"while methyl bromide is less toxic to man than certain fumigants, all persons fumigating with methyl bromide or mixtures containing methyl bromide; or persons entering fumigated rooms, cars, or sheds to open ventilators or to unload fumigated materials, should observe precautions used with other toxic fumigating gas. Experience indicates that adequate precautions will obviate danger of injury by this gas."

Methyl bromide is obtainable in one-pound cans or in cylinders containing 10, 50, or 150 pounds net. In 50-pound cylinders it sells for 70 cents per pound.

Naphthalene

Naphthalene is useful chiefly in tightly closed containers or small rooms for the long time protection of clothing, furs, and woolen fabrics. It is a white, crystalline substance that on exposure to air sublimes slowly forming a vapor that is toxic to insects confined in it. It is not a quick acting fumigant, but will afford long time protection to clothing stored in tight containers if a sufficient quantity is used to compensate for any loss from leakage. It is more economical for this purpose than paradichlorobenzene since only .04 pound of the material is required to saturate the atmosphere in 1,000 cubic feet of space at a temperature of 77° F. It should not be used to fumigate grains or other food products since the vapors impart an odor and taste that is retained. The flesh of animals and poultry fed on materials fumigated with naphthalene becomes tainted with a characteristic, disagreeable flavor. The vapors of naphthalene are non-inflammable and are not considered to be dangerous to human beings, at least for short exposures.

Paradichlorobenzene

Paradichlorobenzene is employed in the same manner and for the same purposes as naphthalene. It is not quite so economical as the latter material since it requires .5 pound to saturate the atmosphere in 1,000 cubic feet of space. It is a white crystalline material that, on exposure to air, sublimes slowly forming a heavy vapor that has an odor more pleasing to some people than that of naphthalene. The vapor is non-inflammable as ordinarly used. However, it will flash at about 158° F. With respect to food products it has the same unfortunate characteristics as naphthalene in that it imparts an obnoxious odor and taste that with animals and poultry is carried through to the flesh.

Sulphur Dioxide

Sulphur dioxide has a limited use for the treatment of empty buildings or rooms in barracks and houses that do not contain materials likely to be injured by the bleaching or corrosive effects of the fumes. It is usually produced in fumigation work by the burning of sulphur, although it can be obtained in liquid form in cylinders. It is non-inflammable, highly toxic to insects, and, like hydrocyanic acid, is rapid in action. The irritating effects of even low concentrations makes it unlikely that human beings will willingly enter a dangerous concentration. When breathed it is quickly absorbed by the moist surfaces of the respiratory tract resulting in severe inflammation and edema.

FUMIGATION OF WAREHOUSES, BARRACKS, HOUSES, ETC.

In the fumigation of large enclosures, such as warehouses, barracks, houses, and similar buildings, success will depend largely on the proper preparation of the building, the correct choice of a fumigant, the use of an adequate supply of the fumigant, its proper application and the circumstances under which it is used. The various factors involved will be discussed in order.

Preparation of the Building

It is essential that the building or room be as nearly air-tight as it can be made. All windows should be tightly wedged or sealed, and any broken panes replaced. Loosely fitting window sashes should be sealed with paste and paper or "puttied up" with flour and oil mixed to the consistency of putty. For stripping window frames several types of material can be used: rolls of gummed paper, strips of newspaper smeared with grease or pasted with flour paste, or rolls of fumigators' tape are suitable. Sometimes it is impossible to tighten a window by the ordinary method of sealing or stripping and it is necessary to seal the entire aperture. For this purpose, car-lining paper can be used or, better still, fibre-reinforced, tar impregnated paper.

Small doors leading to the exterior of the building can be tightened with any of the materials used for the windows. Large sliding metal or wooden doors that fit imperfectly can be caulked with the flour-and-oil mixture or with a paste composed of 4 parts of asbestos to 1 part of calcium chloride mixed with a little water. Both these mixtures form an effective seal, yet can be easily removed after fumigation.

Roof ventilators should be thoroughly sealed, also chimneys and other flues.

Temperature

At high temperatures all gases are more active and efficient, and insects are likewise more active and susceptible, hence it is desirable to maintain a high temperature in the building during the fumigation. For best results a temperature of at least 75° F. is desirable, although with hydrocyanic acid or methyl bromide it is possible to obtain good results at temperatures as low as 55° F., if it becomes necessary to fumigate under such conditions.

Time of Application

High winds cause the fumigant to drift to one side of a building and to increase the rate of leakage. Fumigation during periods of little or no air movement is desirable.

Method of Application

For best results the fumigant should be applied so that a maximum concentration will be obtained as quickly as possible. This is particularly important in buildings in which the leakage factor is high.

Proper Dosage

In the case of warehouses or store rooms that are filled with highly absorptive commodities, such as feed, it is necessary to use a larger dosage than if it were empty. Similarly a poorly constructed building will require a larger dosage to offset leakage. The experience of the fumigator plays an important part in deciding the dosage.

Choice of Fumigant

From the standpoint of availability, cost, efficiency, and simplicity of application, hydrocyanic acid is the most practical gas for the general fumigation of houses, barracks, warehouses, and buildings of all kinds. Methyl bromide can be used if the building or enclosure is of modern, concrete or brick construction, and in certain cases sulphur dioxide is useful for the treatment of rooms in barracks or houses. Chloropicrin, although less popular than hydrocyanic acid and methyl bromide, owing to the lachrymatory nature of the fumes and the tenacity with which they cling to fumigated commodities, can also be employed.

PRECAUTIONS TO TAKE IN ALL FUMIGATIONS

In the fumigation of warehouses, barracks, houses, or any structure, it is necessary to take certain precautions to safeguard persons that are likely to be in the vicinity of the building on business or otherwise. Before the fumigant is introduced the building must be searched to determine that no persons are left inside. Adequate warning signs should be posted, the building locked up and guards posted to prevent the entry of anyone after the gas is introduced and for the entire period that the building is under fumigation. During ventilation the guards should be instructed to prevent anyone besides the fumigators from entering the building until it has been declared free from gas.

If the building to be fumigated adjoins other buildings, these should be vacated during the fumigation.

DANGER FROM ABSORBED FUMIGANTS

Many commodities stored in warehouses that are fumigated absorb large quantities of the fumigant which are slowly given off after the fumigation is over. If warehouses or rooms that have been fumigated and ventilated are closed up tightly, it is quite possible that fumigated commodities stored therein may give off a sufficient amount of gas to be dangerous to anyone entering the building at a later date. If possible warehouses or rooms that contain large quantities of fumigated commodities should be kept open for several days to allow the dangerous vapors to escape.

WAREHOUSE FUMIGATION WITH HYDROCYANIC ACID

Hydrocyanic acid gas is the most efficient fumigant known for the treatment of structures that are not completely air-tight, since it kills with great speed. It is relatively inexpensive, will not injure the dry staple foodstuffs, and is non-inflammable at concentrations used in warehouse fumigation. Although it is one of the most deadly gases used in fumigation work it can be handled with relative safety by experienced workers. It is commonly produced in several different ways, but for use in warehouse fumigation it is best produced by pumping it into the building in liquid form from cylinders or by generating it from a mixture of sodium cyanide and dilute sulphuric acid.

Liquid Hydrocyanic Acid

Liquid hydrocyanic acid is more convenient to use for warehouse fumigation than the barrel or pot method by which the gas is generated from sodium cyanide and dilute sulphuric acid. Liquid hydrocyanic

acid can be used wherever a supply of it can be obtained. In outlying posts it is not always practical to use it since the liquid has a tendency to decompose with time and it is not considered safe to store the cylinders for more than 5 months.

After a building has been prepared for fumigation, the liquid hydrocyanic acid is applied entirely from the outside, figure 1. A portable compressor attached to the cylinder forces the gas into the building by means of lines of pressure rubber tubing, or metal piping equipped with spray nozzles. For permanent installations in warehouses, copper tubing is used to pipe the building, a spray nozzle being provided for every 15,000 cubic feet. For temporary work the easily transported rubber tubing is adequate.

Each cylinder of liquid hydrocyanic acid is supplied with an inlet and an outlet valve. The outlet valve is attached to a steel tube connected with the bottom of the cylinder. The inlet valve leads directly into the top of the cylinder, and when the fumigation is about to begin, air is pumped through it into the cylinder by means of a compressor until a pressure of about 100 pounds is obtained. The outlet valve, which in the meantime has been connected with the inlet pipe to the building, is then opened and the liquid is forced into the building. The pressure must be maintained until all the liquid has been blown through the pipes into the building. The pipe lines are then blown clear and the inlet tubes capped.

While applying the gas the fumigator should wear a gas mask or have one handy to put on in case of leaks or breaks in the pipes, and should wear protective outer clothing that can be slipped off easily in case it accidently becomes soaked with the liquid.

Figure 1.--Fumigating a warehouse with hydrocyanic acid gas, using the liquid method. The liquid hydrocyanic acid in the cylinder on the scales is being forced by air pressure generated by a small electrically driven compressor, through the rubber tubing from the cylinder to the piping system installed inside but protruding through the walls.

A dosage of 8 ounces of liquid hydrocyanic acid for every 1,000 cubic feet of space is adequate for the treatment of empty warehouse space, or space filled with clothing and commodities other than bagged foodstuffs. Warehouses loaded with large quantities of bagged flour, feed, grain or similar materials are difficult to fumigate successfully with even very heavy dosages of hydrocyanic acid.

Generating Hydrocyanic Acid Gas from Sodium Cyanide and Dilute Sulphuric Acid

This method is cheaper, though more laborious, than the use of liquid hydrocyanic acid as described above, but can be used where supplies of liquid hydrocyanic acid are not available. It is known as the barrel or pot method because the chemicals used in the process are placed together in a barrel or similar container, figure 2.

Chemicals required.- Sodium cyanide (96 to 98 percent, containing 54 percent of available HCN), a commercial grade of sulphuric acid (66° Baume), and water, are the only materials required. For best results they should be mixed according to the following formula:

Sodium cyanide	1 pound
Sulphuric acid	1 1/2 pints
Water.	2 pints

Sodium cyanide is a white crystalline substance, which for fumigation purposes is prepared in egg-shaped lumps weighing approximately one-half ounce or 1 ounce each. It is a violent stomach poison, and also can cause serious poisoning by being absorbed through open cuts or through the mucous surface of the eyes. For this reason it is best handled with a scoop or shovel or with gloved hands.

Figure 2.--Man wearing gas mask about to lower a bag of sodium cyanide into a barrel containing sulphuric acid and water.

Sulphuric acid is a heavy, colorless liquid when pure, but the commercial acid used in large-scale fumigation work is slightly discolored, or murky, owing to impurities. It is highly corrosive and will cause injury if it spatters on the clothing or body of the operator or upon the floor. It can be purchased in 11-gallon carboys. When large quantities of acid are required, a tilting frame will be found convenient in pouring the acid from the carboys, or an acid pump can be used.

Proper Order in Placing Chemicals in Generator.- To generate hydrocyanic acid gas by this method, the operator should first pour the water into the generator and then add the acid. If the procedure is reversed, the reaction is so violent that the operator may be dangerously burned by the spattering of the acid-water mixture. As soon as the sodium cyanide comes in contact with the mixture of water and acid an immediate chemical reaction takes place during which hydrocyanic acid gas is given off. The pure gas is colorless, but when mixed with steam produced by the chemical reaction it has the appearance of a light bluish smoke. It has an odor resembling that of peach kernels.

The Dosage.- The dosage is computed on the basis of the quantity of sodium cyanide required. For warehouse fumigation one pound of sodium cyanide will produce enough gas to fumigate 1,000 cubic feet of space, if the building is of reasonably tight construction.

The Generator.- For large-scale fumigation a water-tight 50-gallon heavy wooden barrel is the most suitable generator to use. Metal containers must not be used because of their susceptibility to corrosion by the acid. Each barrel will hold a maximum charge of 30 pounds of sodium cyanide, or enough to fumigate 30,000 cubic feet of space. When it is necessary to fumigate small rooms of a few thousand cubic feet as

separate units, earthenware or stone jars of appropriate size can be used. A 4-gallon jar will hold a charge of 3 pounds of sodium cyanide.

Each generator should be set in a galvanized-iron washtub in which has previously been placed a pailful of water containing several handfuls of washing soda. This precaution provides for catching and neutralizing small quantities of the acid-water mixture that may leak out of the barrel.

If three or four bricks are placed in the bottom of the washtubs for the barrels to rest on, they will not become stuck in the tubs.

Placing the Generators.- If possible, the generators should be spaced evenly over the floors to obtain an even distribution of the gas. If necessary, however, the generators for one floor can be grouped together near the exit. The gas will eventually be dispersed to all parts of the enclosed space, though not so rapidly as when the generators are scattered evenly over the floor.

Generating the Gas.- After the warehouse has been prepared for the fumigation and all the generators have been placed in their proper positions, the water and acid are measured out and distributed. The acid can be poured from the carboys into heavy galvanized-iron buckets, which will resist the action of the acid long enough for it to be distributed without accident. If jars are used for generators, the acid must be poured into the water slowly, lest the heat developed by the chemical reaction between the water and acid cause the jars to break.

After it has been determined that none of the barrels leak, the sodium cyanide, which has been weighed in the proper quantities and placed in paper bags, should be placed beside the generators. The

sodium cyanide should not be placed in the bags until the latest possible moment; otherwise, the cyanide takes up moisture from the atmosphere, thus softening the paper so that the bags may break when lifted.

When all the precautionary measures have been taken, and as soon as possible after the water and acid have been mixed, the fumigating crew, starting with the generator farthest from the exit and on the top floor in the case of a building of more than one story, should lower the bags gently into the generators. The man in charge should not take part in the lowering of the cyanide, but should watch the crew to see that none of the generators is skipped, and that none of the men gets into trouble.

Since the gas is generated as soon as the acid-water mixture comes in contact with the sodium cyanide, the supervisor and operators engaged in dropping the cyanide should wear gas masks.

Emptying the Generators.- When the fumigation is finished and the building has been thoroughly ventilated, the residue must be emptied from the generators. Sometimes the chemical reaction is incomplete, because some of the sodium cyanide has not come in contact with the acid-water mixture. When the generator is moved, the contents are shaken up and small quantities of gas may be given off. For this reason the operator should breathe as little as possible while handling the barrels and should not hold his head over the barrel.

The residue, which is poisonous, can be disposed of by pouring it into a hole in the ground and covering it with soil. When disposing of the residual material after fumigation, the operator should never bend over the hole, but should stand to windward and lean away from the hole as much as possible.

Length of Exposure.- The efficiency of a fumigation is proportional to the length of exposure and if the fumigant can be held in an enclosure a long exposure period is desirable. However, few buildings will hold an appreciable concentration of hydrocyanic acid for more than 24 hours, hence it is rarely practical to extend the exposure for a longer period. On the other hand it is possible to obtain excellent results in much shorter periods and a 12-hour period may suffice if time is short.

Use of Hydrocyanic Acid Discoids

For the treatment of small warehouses or storage rooms hydrocyanic acid discoids will be found convenient and useful, although their use is not recommended for any but professional fumigators. Wafer-like discoids of an inert material, each containing approximately one-half ounce of absorbed liquid hydrocyanic acid, are available packed in sealed metal cans of various sizes, and sold on the basis of the net content of hydrocyanic acid. When the cans are opened and the discoids scattered over the floor the liquid hydrocyanic acid evaporates and diffuses to all parts of the enclosure.

The proper number of cans of discoids should be placed in each room or floor of the warehouse if there are more than one, and fumigation should be started on the top floor or the room farthest from the exit. One man should open the cans, using a special can opener (figure 3) that makes a clean cut close to the rim, while two or more men, if necessary, take the open cans and scatter the discoids over the floor. (figure 4).

Discoids should not be placed directly on painted or varnished floors or woodwork, for the liquid hydrocyanic acid is likely to injure the finish. A layer of two or three thicknesses of paper provides

Figure 3.-- Man protected by gas mask, removing the top from a tin can containing discoids impregnated with liquid hydrocyanic acid.

Figure 4.— Furnished room being fumigated with hydrocyanic acid gas generated from discoids. The discoids are shown scattered over a piece of paper to prevent any liquid from coming in contact with the floor.

adequate protection against any liquid that may ooze from the discoids. When discoids are used, the fumigators are exposed to a certain concentration of the gas while they are opening the cans and distributing the contents. Good gas masks will protect them against poisonous fumes, but there is also some danger from the direct absorption of hydrocyanic acid gas through the skin. The fumigating crew should be large enough

so that the distribution of the fumigant will be speedy and no one man will be exposed to the gas for a dangerously long period.

When large numbers of discoids are used, it is advisable to chill the cans before fumigating. This retards the evolution of the gas and thus increases the safety of the operation. If solid carbon dioxide or "dry ice" is available, a liberal quantity thrown over the tops of the cans in each open case a few hours before fumigation will chill the discoids.

As in the case of liquid hydrocyanic acid, a dosage of 8 ounces per 1,000 cubic feet of space should be used for general fumigation purposes.

After the fumigation and ventilation of the building, the spent discoids and the empty cans can be gathered and disposed of. At the end of a 24-hour fumigation the discoids do not retain more than a trace of hydrocyanic acid.

Use of Calcium Cyanide

Calcium cyanide in dust form is used in much the same way as the discoids for the treatment of small warehouses or enclosures. On exposure to air the powder absorbs moisture and a chemical reaction takes place by which hydrocyanic acid gas is given off.

Applying the Powder.- The required number of cans of calcium cyanide are distributed throughout the building. They are then opened and their contents scattered over the floor in a layer not more than half an inch thick. To facilitate removal of the dust after the fumigation, it may be scattered

on strips of paper previously laid on the floor, although it is sometimes placed directly upon the floor (fig. 5). Each can of fumigant is equipped with a special perforated top, which the fumigator puts in place of the friction top when he is ready to use it.

Figure 5.--Warehouse being fumigated with hydrocyanic acid gas generated from calcium cyanide. The calcium cyanide in dust form is spread on the floor, usually from cans with perforated covers.

Inasmuch as the gas is given off very rapidly after the dust is exposed to the air, the fumigator should wear a gas mask while distributing it. As in the case of the discoids, he should begin distributing the dust at the point farthest from the exit, so that he will be working away from the gas that is being given off.

After the fumigation, the paper on which the dust is spread can be rolled up and thrown away, or the dust can be swept from the floor and placed in containers, to be disposed of immediately. The residue, which is mostly calcium hydroxide, is likely to absorb some of the hydrocyanic acid from the air; hence it is advisable to dispose of it outside the building, where small quantities of escaping hydrocyanic acid gas will harm no one. After the hydrocyanic acid has been given off, the residue is nonpoisonous. As the dust may be blown about while the building is being ventilated, it should be removed as soon as possible.

To calculate the quantity of calcium cyanide needed for a fumigation, it is necessary to know the percentage of available hydrocyanic acid it contains. This percentage will be found on the label of the can. If, for example, the dust contains 50 percent of available hydrocyanic acid, 1 pound will give off as much gas as 8 ounces of liquid hydrocyanic acid or 1 pound of sodium cyanide. Calcium cyanide ranges in price from $1.60 per pound in 1-pound cans to $1.20 per pound in 25-pound cans.

Ventilating the Warehouse after Fumigation

After the fumigation and regardless of the method used to generate hydrocyanic acid gas the building should be aired out by opening the doors and windows. If possible these should be opened from the outside. If not, windows and doors can be opened from the inside by workmen wearing gas masks. In this latter operation two men should work together to guard against accident.

WAREHOUSE FUMIGATION WITH METHYL BROMIDE

For the fumigation of modern concrete or brick warehouses of tight construction, there is no better fumigant than methyl bromide. It is excellent for the treatment of empty warehouse space or space filled with bagged, whole grains or feeds. It should not be used to treat warehouse space loaded with ~~milled cereals or~~ foods with a high fat content that are intended for human consumption.

It can be applied in very much the same manner as liquid hydrocyanic acid by being forced through a temporary or permanent piping system, or in small warehouses the cylinders can be placed inside the warehouse and the gas released by opening the valves. Sufficient air pressure is added by the manufacturer to insure the ejection of the fumigant from the cylinders when the valve is opened unless the liquid has to be forced through a system of pipes and spray nozzles. In that case the pressure in the cylinders should be increased to 150 pounds by means of compressed air. A dosage of 1 pound of the liquid per 1,000 cubic feet of space is sufficient for both empty and filled warehouses.

An overnight fumigation is sufficient, after which the warehouse can be opened for ventilation. The same precautions should be taken in opening up warehouses fumigated with methyl bromide as with those fumigated with hydrocyanic acid.

CHLOROPICRIN AS A WAREHOUSE FUMIGANT

For the treatment of empty warehouse space chloropicrin can be applied at the rate of 1 pound per 1,000 cubic feet of space. The liquid chloropicrin can be drawn off from the 100-pound cylinders into 6-quart sprinkling cans by workmen wearing gas

masks and applied by sprinkling on burlap sacks spread on the floor. Care should be taken to keep the liquid from coming into contact with varnished woodwork. Care must also be taken to avoid spattering the liquid on the hands or feet, since blistering may result.

As is the case with other toxic fumigants that are applied by hand, it is desirable to start applying the material at the point most distant from the exit and gradually work toward the door.

The same precautions must be observed in opening the building for aeration after the fumigation as employed with any other poisonous gas. Considerable time, sometimes several days, is usually required to ventilate a building after fumigating with chloropicrin owing to the tenacity with which the vapors cling.

FUMIGATION OF BARRACKS, AND HOUSES WITH HYDROCYANIC ACID

In the fumigation of barracks and houses with hydrocyanic acid for the control of bedbugs, cockroaches, clothes moths, carpet beetles, or other household pests, the same methods can be employed as described for the fumigation of warehouses. It is, of course, unlikely that there would be any occasion to permanently pipe a house or barracks for the use of liquid hydrocyanic acid, but temporary lines of pressure rubber hose can be used to conduct the liquid fumigant to all parts of a building. Many fumigators prefer to use the "barrel" method of generating the gas for the treatment of small buildings, although the use of discoids is also popular. In any case the same precautions must be taken to safeguard the fumigators, and to prevent people from entering the building while it is under fumigation, as described for warehouse fumigation.

In houses or barracks, mattresses, bed clothing, and other furnishings may retain enough hydrocyanic acid after a fumigation to be dangerous to people using them or confined in rooms with them. This is particularly true during cold weather. After a fumigation has been conducted under such conditions, and the rooms of the building have been ventilated, the heat should be turned on and the contents allowed to warm up so that the gas held by the mattresses, blankets, etc. will be given off. The rooms can then be aired out again and the windows left open until there is no more danger. If possible, fumigated blankets and mattresses should be taken outdoors where they can be beaten and aired thoroughly before being used.

FUMIGATION OF BARRACKS AND HOUSES WITH CHLOROPICRIN OR METHYL BROMIDE

In a similar way houses, individual rooms or barracks can be successfully treated with either chloropicrin or methyl bromide and at the same dosages and periods of exposure recommended for warehouse fumigation. Methyl bromide should be used only in tight buildings of concrete, stone, or brick construction. Any leather goods should be removed from the buildings before fumigation, since it has been found that in some cases leather products retain a peculiar odor after fumigation with this gas. It will be found that chloropicrin clings tenaciously to fumigated furnishings so that it may take several days in some case to entirely get rid of the eye-irritating vapor in the air of a fumigated building.

FUMIGATION OF ROOMS WITH SULPHUR DIOXIDE

The burning of sulphur in rooms or houses is one of the oldest known methods of fumigation. It is rather difficult to confine the heavy vapors unless the room is exceptionally tight, and the gas

itself is not so toxic as hydrocyanic acid. Fumigation with sulphur dioxide is quite simple, however, and is considered to be safe owing to the fact that the fumes are so irritating that nobody will willingly stay in a concentration strong enough to be dangerous.

Sulphur dioxide is usually generated by burning sulphur. For the fumigation of houses or rooms, sulphur candles may be purchased ready for burning. Since sulphur alone does not burn readily it is often dampened with alcohol to hasten the process. Sulphur dioxide is non-inflammable, but there may be danger unless precautions are taken to prevent the burning sulphur from setting fire to the surroundings. Two pounds of sulphur should be burned for every 1,000 cubic feet of space. The room should be kept closed for 12 to 24 hours before being aired.

Sulphur dioxide fumes corrode metals, bleach fabrics and wallpapers, and discolor paint. This action is particularly severe if there is much moisture in the air.

Liquid sulphur dioxide can be obtained in cylinders and can be used for fumigation purposes if desired. Two pounds of the liquid sulphur dioxide is approximately equivalent to the gas produced from burning 1 pound of sulphur. The use of sulphur dioxide is recommended only when other fumigants are unavailable or for some reason cannot be used.

FUMIGATION OF WOOLENS AND FURS

Naphthalene and Paradichlorobenzene

Woolens and furs, such as blankets, clothing, fur-lined aviator's garments, helmets, and boots require protection constantly when in storage. The most universally employed fumigants are the vapors of

naphthalene and paradichlorobenzene. The effectiveness of these vapors depends upon maintaining them in sufficient concentration long enough to either stupefy or kill the destructive insects. Both chemicals can be depended upon when used in thoroughly tight enclosures, but are not dependable in open storage or loose containers which permit the vapors to escape. Because heavier-than-air vapors are formed by the evaporation of the crystals, the supply of crystals must be replenished from time to time, the frequency of retreatment depending upon the ease with which the vapors can escape. From 2 to 4 pounds of crystals should be used to each 100 cubic feet of tight space. For prolonged storage, the more rapidly evaporating and expensive paradichlorobenzene has no advantage over flake naphthalene in spite of its more agreeable odor. The odors of both chemicals disappear from articles within a few days after they have been ventilated thoroughly.

Clothing, blankets, and other susceptible materials to be protected with naphthalene or paradichlorobenzene should be packed tightly in wooden boxes well lined with heavy unbroken paper. Crystals should be sifted between the layers of the commodity as the packing proceeds. All stages of fabric pests in supplies thus packed will be killed provided the materials are tightly packed in a tight container.

An excellent method of employing naphthalene is to construct tight rooms sufficiently large to contain materials to be protected, and keep the air of such rooms so impregnated with the vapors of naphthalene that the eyes and nose of a person entering the room will sting. Such rooms are employed in the warehousing industry for protection against fabric pests. They are cheaply operated and readily worked, and make it unnecessary to handle the supplies stored therein when replenishment of the chemical is necessary. The chemical is exposed about the edges of the room, in trays if desired, but more often shoveled about where it does not interfere with the workmen during their brief stays in the room.

Ethylene Dichloride--Carbon Tetrachloride Mixture

When rooms stocked with naphthalene are not desired, storage in tightly constructed rooms that can be fumigated periodically with the ethylene dichloride--carbon tetrachloride fumigating mixture has found favor in the storage industry. Such rooms are equipped with racks from which clothing can be hung in catalogue order. Shallow trays suspended from the ceiling provide for the evaporation of the liquid fumigant either poured into them or pumped into them from a container outside the room. All large rooms are equipped with exhaust fans, and other provisions for removing the fumigant after the exposure period of 12 hours. The Haskelite Manufacturing Corporation, Chicago, Illinois, has been the only source of supply for the equipment of practically all fumigable storage rooms in use today. The ethylene dichloride--carbon tetrachloride fumigating mixture should be used at the rate of 14 pounds (about 5 quarts) per 1,000 cubic feet of storage space. Fumigations of these storage rooms are made as a matter of routine about once a month during warm weather. Fumigable storage rooms are usually supplemented with small receiving vaults of about 500 cubic feet capacity in which materials are first fumigated before being stored in larger rooms.

Ethylene Oxide--Carbon Dioxide Mixture

The ethylene oxide--carbon dioxide mixture, or any other effective fumigant that will not damage fabrics, can also be used in such storage rooms. The ethylene oxide--carbon dioxide mixture should be used at the rate of 15 pounds per 1,000 cubic feet of space and can be applied from outside the storage room through a simple piping system equipped with one or more spray nozzles. The natural pressure of the gas mixture in the cylinder will force it into the room. If no piping system is available and the room

is large enough to require the entire contents of a cylinder, the cylinder can be placed inside the room and the contents discharged by opening the valve. In such cases it is well to lash the cylinder to a support, otherwise the pressure of the gas may overturn the cylinder when the valve is opened. If the floors are varnished, painted or shellacked provision should be made to protect them from any liquid that may drip from the cylinder.

Household furnishings, such as bedding, furniture, rugs, etc. can also be fumigated in such storage rooms or they can be treated in airtight atmospheric fumigation vaults, such as are described in the following pages.

FUMIGATION IN TIGHT CHAMBERS OR VAULTS

For the treatment of small lots of food supplies, animal feeds, household furnishings, garments, fabrics, etc., gas-tight fumigation chambers or vaults can be used to advantage. These can be constructed of any material that can be made gas-tight. The most satisfactory are of concrete, brick, hollow tile, or of wooden frame with a sheet metal lining. The latter type is quite popular and can be constructed at low cost. The simplest form of construction of this type of vault consists of a frame work of studding on the outside, with a lining of sheet metal on the inside. The joints between the sheets may be either welded or made tight with asphalt strips It is, of course, more desirable to reinforce the metal lining on the outside with a layer of board sheathing. Doors can be of the refrigerator type or of the same type of construction as the walls of the vault. A gasket of canvas-covered live rubber affords a gas tight seal. A false floor should be provided, also an exhaust fan with a ventilating stack leading outside the building housing the vault. Vaults of brick or hollow tile should have a coating of Keen's cement and one or two coats of paint on the inside.

A plan for an ideal vault is shown in figure 6. It can be made in any one of several types of construction and is supplied with a fan for either circulating the fumigant in the vault or exhausting the vapors; tubing and spray nozzles for introducing highly volatile fumigants; marine port lights; thermometer; and a pilot light to indicate when a fumigation is in progress.

Vault Fumigation Methods

The actual process of fumigation in a vault is quite simple. The commodity to be treated is loaded into the vault either by hand, or run in on trucks or skids. The door is then closed and the fumigant applied after which the vault is left locked for the duration of the exposure. At the end of the fumigation the exhaust fan is turned on and allowed to run until the fumes not absorbed by the fumigated commodity have been removed from the vault. While the vault is being unloaded the exhaust fan should be kept running for the protection of the workmen. In some cases auxiliary fans may be required to supply fresh air for the workmen, unless gas masks are worn.

The length of the exposure period will usually depend upon circumstances. If there is no urgency a 24-hour exposure or even longer period should be allowed, since the toxic action of a fumigant is in direct proportion to the length of the exposure. In the atmospheric fumigation of closely packed materials, such as bagged milled cereals, penetration of the fumigant is slow.

The temperature of the commodity to be fumigated is of vital importance. If the product is cold, penetration by fumigants is greatly retarded, adsorption of the gas is increased and higher dosages are required. It is doubtful whether it is practical to fumigate products such as bagged milled cereals in atmospheric vaults at temperatures below 70° F.

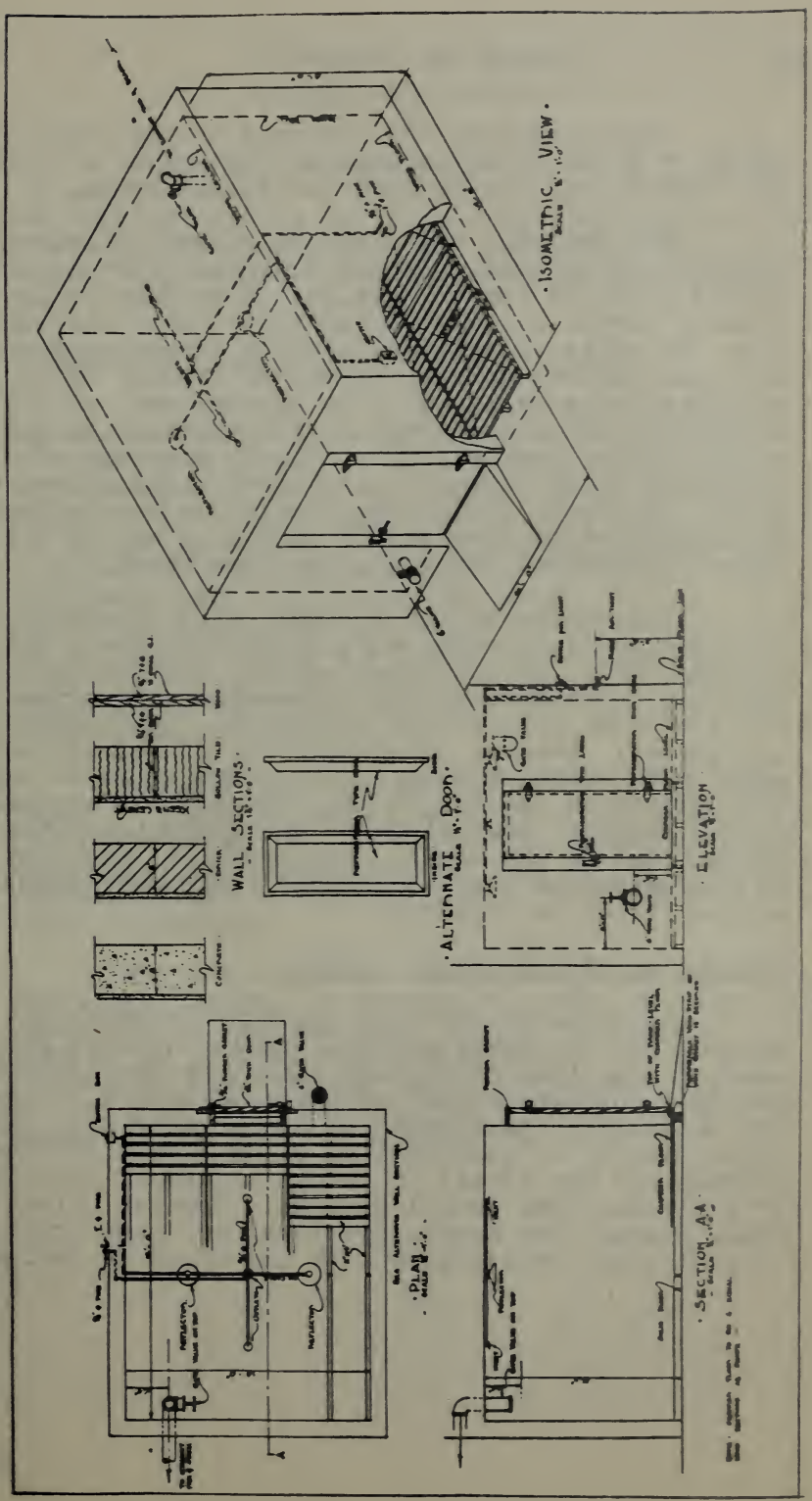

Figure 6. - Plans for fumigation vault

Circulation of the fumigant in the vault by means of a fan is advantageous. By use of a by-pass the exhaust fan can be used for this purpose.

For applying the fumigant several different methods can be used. Liquid fumigants that are not highly volatile are usually run in by gravity or compressed air into shallow evaporating pans suspended from the walls or ceiling. Volatile fumigants, such as liquid hydrocyanic acid, methyl bromide or the ethylene oxide-carbon dioxide mixture are usually introduced through a short piping system with one or more spray nozzles. The natural pressure of a majority of these gases is sufficient to introduce the dosage required. Hydrocyanic acid gas can be generated for use in atmospheric vaults by any of the methods described for warehouse fumigation.

The choice of the fumigant will depend upon its availability, cost, and suitability for treating the product to be fumigated, except that methyl bromide cannot be recommended for ~~milled cereals or~~ fatty foods because they retain the bromine in deleterious quantities. Leather goods also should not be fumigated with methyl bromide. The quantity to be used will depend on the length of exposure, the temperature of the product, the nature of the product and the size of the load in the vault. For practical purposes it is convenient to base all dosage recommendations on vaults filled to capacity.

Fumigation of Dry Staple Foods

It is not worthwhile to fumigate badly infested flour or other milled cereals intended for human consumption since they cannot be reconditioned for food purposes by any practicable method. They are not readily penetrated by hydrocyanic acid gas, chloropicrin, or the ethylene oxide-carbon dioxide mixture and are likely to retain injurious residues if fumigated with methyl bromide. However, rice or other grains, dry beans, dry peas, or dried fruit may be fumigated successfully with any of these fumigants.

In general a dosage of from 1 to 2 pounds of methyl bromide or hydrocyanic acid, 2 to 3 pounds of chloropicrin or 20 to 30 pounds of the ethylene oxide-carbon dioxide mixture per 1,000 cubic feet of space will be required. An exposure period of 24 hours should be allowed.

Fumigation of Cured Meats and Cheeses

Infestation of cured meats and cheeses by mites, ham beetles, or skippers sometimes makes fumigation necessary. Meat-storage houses that are reasonably tight can usually be successfully fumigated with hydrocyanic acid at the rate of 1 pound of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet for a period of 24 hours. Such treatment does not injure the meats, but if the infestation has penetrated deeply into the meat, it is difficult to get a perfect kill. The Federal meat-inspection regulations require that permission for each fumigation of meat be obtained from the Federal meat inspector.

Cheeses that are protected by an unbroken layer of paraffin can be safely fumigated with hydrocyanic acid, but, owing to the danger of their absorbing large quantities of the gas, unprotected cheeses should be removed from a warehouse that is to be fumigated.

For the treatment of small quantities of cured meats, or cheeses, a fumigation vault or other tight container is recommended. Carbon disulphide at the rate of 10 pounds, ethylene oxide at the rate of 2 pounds, or the ethylene oxide-carbon dioxide mixture at the rate of 20 pounds, per 1,000 cubic feet of space can be used for a period of 24 hours.

FUMIGATION UNDER TARPAULINS

If warehouses are too loosely constructed and no atmospheric vaults are available, a rubberized tarpaulin can be pressed into service to treat individual stacks of supplies. At times it is inconvenient to treat an entire warehouse and the treatment of individual stacks is necessary. Canvas tarpaulins, even those that have been treated to make them waterproof, are not tight enough for this purpose. Firms from which rubberized tarpaulins can be obtained are listed at the end of this paper.

In figure 7 is shown a pile of bagged seed partially covered with a tarpaulin in preparation for fumigation with methyl bromide. The bags are arranged so that a space is formed at the top of the pile to permit more rapid diffusion of the fumigant. A piece of rubber tubing from the applicator conducts the methyl bromide to the dome of the stack. Care must be taken to weight down the edges of the tarpaulin tightly to prevent loss of the gas.

Dosages and exposure periods are similar to those used in tight vaults. In applying hydrocyanic acid gas in tarpaulin fumigation the use of cans of HCN discoids will be found convenient.

In fumigation under tarpaulins the same precautions must be taken as with any other type of fumigation in which poisonous gases are used. No one must be allowed to remain in enclosures containing stacks of commodities that are being fumigated under tarpaulins.

Figure 7. - Pile of bagged seed partially covered with tarpaulin in preparation for fumigation with methyl bromide. (Courtesy of N. MacLean)

BIN FUMIGATION

Small supplies of grain stored in bins for animal feeds that have become infested can be successfully treated with the ethylene dichloride-carbon tetrachloride mixture at the rate of 6 gallons, or with carbon disulphide at the rate of 3 gallons, per 1,000 bushels of grain. Both fumigants are applied by sprinkling them over the surface of the grain in the bin. Small bins can be treated with the aid of an ordinary sprinkling can. Owing to the fire hazard connected with the use of carbon disulphide this material should rarely be used and then only when the bin to be treated is segregated from other buildings and danger from fire can be controlled.

Small quantities of both of these materials can be applied without the use of a gas mask, but any extended use requires the wearing of one. Large quantities of the ethylene dichloride-carbon tetrachloride mixture can be applied from outside large bins with the aid of a bucket sprayer or a larger power sprayer. It is dangerous to attempt to apply carbon disulphide in this manner.

WHERE FUMIGATION CHEMICALS AND EQUIPMENT CAN BE OBTAINED

The accompanying list of concerns and their products is included for the information of the users of this circular, without given or inferred guarantee of the reliability of the firms or endorsement of their individual products. No attempt has been made to make the list fully complete and no discrimination is intended or implied against firms whose names or products are not listed.

Calcium Cyanide

American Cyanamid & Chemical Corp., 30 Rockefeller Plaza, New York, New York

Carbon Disulphide

Dow Chemical Company, Midland, Michigan
E. I. du Pont de Nemours & Company, Wilmington, Delaware
Mallinckrodt Chemical Works, 3600 North Second Street, St. Louis, Missouri
Stauffer Chemical Company, Inc., 420 Lexington Avenue, New York, New York
Wheeler, Reynolds, & Stauffer, 624 California Street, San Francisco, California

Carbon Tetrachloride

American Cyanamid & Chemical Corp., 30 Rockefeller Plaza, New York, New York
J. T. Baker Chemical Company, North Phillipsburg, New Jersey
Diamond Alkali Corp., 436 Seventh Avenue, Pittsburgh, Pennsylvania
Dow Chemical Company, Midland, Michigan
Sonneborn Sons, Inc., 88 Lexington Avenue, New York, New York

Chloropicrin

Innis, Speiden & Company, 117 Liberty Street, New York, New York
Ansul Chemical Company, Marinette, Wisconsin
Dow Chemical Company, Midland, Michigan

Ethylene Dichloride--Carbon Tetrachloride Mixt

Carbide & Carbon Chemicals Corp., 30 East 42nd Street, New York, New York
Dow Chemical Company, Midland, Michigan

Ethylene Oxide--Carbon Dioxide Mixture

Carbide & Carbon Chemicals Corp., 30 East 42nd Street, New York, New York

Gas Masks

Acme Protection Equipment Company, 3616 Liberty Avenue, Pittsburgh, Pennsylvania
E. D. Bullard Company, 275 Eighth Street, San Francisco, California
Davis Emergency Equipment Company, 55 Van Dam Street, New York, New York
Mine Safety Appliances Company, Braddock, Thomas and Meade Streets, Pittsburgh, Pennsylvania
Willson Products Company, Inc., Reading, Pennsylvania

Hydrocyanic Acid, Liquid

American Cyanamid & Chemical Corp., 30 Rockefeller Plaza, New York, New York - Kansas City, Missouri - Azusa, California

Hydrocyanic Acid, Discoids

American Cyanamid & Chemical Corp., 30 Rockefeller Plaza, New York, New York - Kansas City, Missouri - Azusa, California

Sodium Cyanide

American Cyanamid & Chemical Corp., see address above.
E. I. duPont de Nemours & Company, Inc., The R. & H. Chemicals Department, Wilmington, Delaware - Boston, Massachusetts - Charlotte, North Carolina - Chicago, Illinois - Kansas City, Missouri - New Orleans, Louisiana - San Francisco, California
Hardy, Inc., Charles, 415 Lexington Avenue, New York, New York
Jungmann & Company, Inc., 157 Chambers Street, New York, New York
Mallinckrodt Chemical Works, 3600 North Second Street, St. Louis, Missouri

Sulphuric Acid

Most of the above firms and many others. Probably available locally.

Methyl Bromide

Dow Chemical Company, Midland, Michigan - New York City - St. Louis, Missouri - Chicago, Illinois
E. I. du Pont de Nemours Company, Inc., see address above.
Liquid Carbonic Corp., 3100 South Kedzie Avenue, Chicago, Illinois

Rubberized Tarpaulins

Crawford Manufacturing Company, Inc., 3rd & Decatur Streets, Richmond, Virginia
Pioneer Rubber Mills, 353 Sacramento Street, San Francisco, California
Universal Rubber Manufacturing Company, 958 Harrison Street, San Francisco, California

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